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Spatial Differentiation in Life Cycle Impact Assessment

A decade of method development to increase the environmental realism of LCIA

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During the life cycle of a product, it causes release of pollutants at many different locations. The location of a given source and the conditions of its surroundings strongly influence the fate of the emitted pollutants and their subsequent exposure of possible sensitive receptors. Even today, this source of variation is usually neglected in most Life Cycle Assessment (LCA) case-studies, although it has been realised for more than a decade that the pattern of impacts predicted by site-generic Life Cycle Impact Assessment (LCIA) in some cases deviate significantly from the actual pattern of impacts, and that this may have serious implications for the validity of the conclusions drawn from the LCA (Potting and Blok 1995, Wenzel et al. 1997). Characterisation modelling of substance emissions in commonly used LCIA is typically focused on inherent properties of the substances while the environment is represented as a standardised or generic 'unit world' with average or generic characteristics in which a 'typical' fate, exposure and fate pattern of the substance can be modelled in a simplified manner.

The absence of spatial differentiation in characterisation has been debated from the very beginning of LCIA (Consoli et al. 1993, Fava et al. 1993). A series of contributions to the SETAC-Europe publication 'LCA News' nicely reflects the different opinions at that time. A lively discussion was initiated by doubts expressed by Perriman (1995) about the credibility of LCIAs without spatial differentiation. The response of Helias Udo de Haes and colleagues (White et al. 1995) provides a good summary of the main line of thinking of that time: Spatially differentiated characterisation was typically considered to involve some kind of site-specific risk assessment and was therefore regarded as not compatible with LCIA. In addition, it was felt that since prediction of actual risks is done already by risk assessment tools, there is no need for inclusion of spatial differentiation in LCA. LCA has historically been seen as a tool for pollution prevention, not avoidance of environmental risks.

A cautious, though marked, change in the discussion about spatial differentiation was initiated by the presentation of

Potting and Blok (1995) at the 4th SETAC-Europe congress in Brussels in 1994. This presentation clearly illustrated the consequences of neglecting spatial differentiation, and by doing so presaged a feasible way to implement spatially differentiated characterisation in LCA. While knowledge of environmental models gradually made spatially differentiated characterisation modelling more feasible and better, the understanding of its relevance grew in LCA circles (Potting and Hauschild 1997a,b). In 1999, Udo de Haes and co-workers on behalf of the Second SETAC working group on Life Cycle Impact Assessment, representing the major part of the LCIA research community in Europe thus wrote: "Spatial differentiation will increase the discriminating power of LCIA; the need to proceed in this alley will increase if the systems to be compared are more alike. Spatial differentiation may be performed because of differences in fate and exposure mechanisms, differences in sensitivity for effects, the difference between background levels determining the working point in the dose-effect curve..." and they continued: "In general, the scientific task groups will start with a non-differentiated generic approach, aiming at global factors for every impact category. One step further concerns the development of spatially differentiated factors, where relevant, i.e. where large variations of fate and exposure or of effect variables are observed". They also noted that "It is important that with spatial differentiation also the global characterisation factors will remain available, because the additional efforts on data acquisition in the inventory phase may not always be possible". (Udo de Haes et al. 1999).

Potting et al. (1998) were the first to establish a set of spatially differentiated factors relating the emission of a given European country to its acidifying impact on the full receiving European area. These factors were derived from the so-called RAINS-model (Amann et al. 1999) that integrates spatially resolved modelling of emission, fate, exposure and effect for a number of impact categories. In the following years, several other projects developed spatially differentiated life cycle impact assessment methodology (e.g. Krewitt

et al. 2001, Seppälä and Huijbregts 2000, Norris 2002, Hettelingh et al. 2005). The Danish LCA Methodology Development and Consensus Creation Project (1998–2002) demonstrated the relevance of spatially differentiated characterisation modelling for the major non-global emission-related impact categories, and provided a methodology with site-dependent factors for each European country (the EDIP2003 methodology, Hauschild and Potting 2005, Potting and Hauschild 2005).

Spatial differentiation is relevant for all non-global impact categories, i.e., all categories for which the level of impact depends on the location of the emission. Impact categories for which spatially differentiated characterisation factors (including effect) or exposure factors have been developed include terrestrial acidification, terrestrial and aquatic eutrophication, photochemical ozone formation and human toxicity. Three levels of spatial differentiation were defined (Potting 2000, Hauschild and Potting 2005).

- **Site-generic.** All sources are considered to contribute to the same generic receiving environment. Like in EDIP97, CML2001 baseline or EcoIndicator 99, *no spatial differentiation* in sources and subsequent receiving environments is performed (Wenzel et al. 1997, Guinée et al. 2002, Goedkoop and Spriensma 2000).
- **Site-dependent.** *Some spatial differentiation* is performed by distinguishing between classes of sources and determining their subsequent receiving environment. Source categories are typically defined at the level of countries or regions within countries (scale 50–500 km). The receiving environment is typically defined at high spatial resolution (scale at maximum 150 km, but often down to a few kilometres). The site-dependent characterisation factors thus include the variation within and between the receiving environments related to each source category in exposure and a priori tolerance to the exposure.
- **Site-specific.** *A very detailed spatial differentiation* is performed by considering sources at specific locations. Site-specific modelling allows large accuracy in modelling of the impact very close to the source. This typically involves local knowledge about the conditions of specific ecosystems that are exposed to the emitted pollutants. However, since the full impact from a source often covers areas extending several hundred to thousand kilometres, a detailed assessment of the impact locally around the source may add little accuracy to the quantification of the full impact.

The spatial information available for individual processes in LCA will typically support site-dependent impact modelling. For most processes it will be known at least in which country it is located, as this information is required to select the appropriate technology of processes and as part of the system delimitation, in order to develop transportation scenarios for the product system. The site-dependent level is thus the relevant level of spatial differentiation for most

characterisation modelling. Incidentally, at least for most airborne emissions, it is also the level of spatial differentiation that is relevant, considering the dispersion of air-borne pollutants with just a moderate atmospheric residence time.

Some product systems will contain materials or processes, for which spatial information is not available at all. Maybe the data has been aggregated over several suppliers to hide sensitive information or to provide average data. For this situation, following the guidance from Udo de Haes et al. 1999, site-generic characterisation factors should be calculated, providing site-generic impact potentials which are compatible with the site-dependent impact potentials calculated for the other parts of the life cycle. In this way the whole life cycle can always be covered by the characterisation. Bellekom et al. (2005) recently tested this approach in their evaluation of the feasibility of site-dependent LCIA for a number of existing case studies. They concluded that it is relatively simple to identify the source country of emissions to perform site-dependent LCIA. Hvid et al. (2005) came to a similar conclusion in a study of the pork product chain, in which site-dependent LCIA also had a major influence on the final conclusions.

The site-specific level of spatial differentiation is often considered unrealistic as an integral part of characterisation modelling for the whole product system. LCA is normally not focused on the local impacts from the product system, and furthermore it will rarely be practical to operate with site-specific modelling for more than a few processes in the product system. Site-specific characterisation may, however, still be used in an additional analysis to qualify the assessment of a few central processes, and it may also be used to provide additional information for the interpretation step of LCA. Its relevance will be largest in studies of product systems where one or a few processes dominate the total life cycle emissions and where the local impacts from these processes are an issue. This may be the case for some industrial production systems (e.g., Sonnemann et al. 2000) or waste treatment systems where impacts from landfills will often be dominant and of a local nature.

Even though differentiation between emission sites has been demonstrated to be more important than differentiation between substances, for impact categories like acidification and photochemical ozone formation (e.g. Hauschild and Potting 2005), site-dependent impact assessment is still not in widespread use. After ten years of methodology development, none of the spatially differentiated characterisation methodologies has yet been integrated in any of the major LCA tools, and site-dependent life cycle impact assessment is therefore still mainly applied in a sensitivity-based approach focusing on the key processes of the product system. The additional requirements to the software development are limited; the database format for the life cycle unit processes typically already has a field for geographical information, and this needs to be linked to the choice of characterisation factor. It is clear that the characterisation has to be done on an inventory which is disaggre-

gated at the process level, but this also ought to be feasible. The reason why spatial differentiation is not supported in the impact assessment part of the major LCA tools seems to be that there is little pressure from the user, the LCA practitioner. The slow acceptance of site-dependent impact assessment by LCA practitioners is contrasted by the recent raising interest in the community of integrated assessment to use this methodology for studies in support of European policies (Hettelingh et al. 2005).

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